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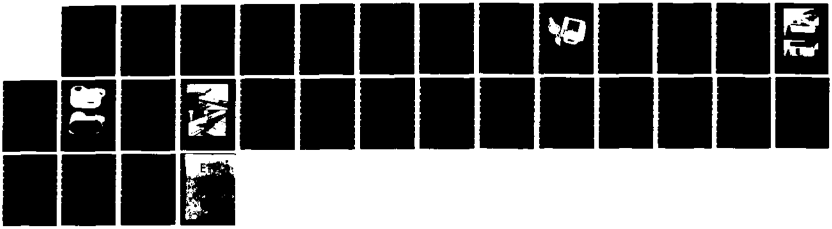

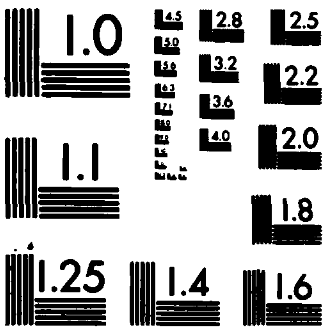

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ELECTRIC MOISTURE METERS FOR WOOD

USDA FOREST SERVICE
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FPL-6
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U.S. DEPARTMENT OF AGRICULTURE
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MADISON, WIS.

ELECTRIC MOISTURE METERS FOR WOOD[1]

By

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ABSTRACT

Electric moisture meters measure moisture content of wood in terms of its electric resistance or dielectric properties, which vary reasonably consistently with moisture contents under about 30 percent. Moisture meters may be either handheld or stationary.

Readings of these meters are affected by such factors as species, temperature, chemical treatments, moisture distribution, operator skill, and others. Information is given here either to correct for these factors or to minimize errors that they may cause.

The two major classes of these meters are the resistance type and the dielectric type, each with its particular advantages. A list of suppliers of these instruments is included.

CONTENTS

[1] This publication replaces U.S. Forest Service Research Note FPL-08, issued in 1963 under the same title by Forest Products Laboratory.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

INTRODUCTION

Moisture content affects most of the important properties of wood, and can vary widely depending on the environment and history of the wood. For this reason, effective use of wood and wood-base materials requires efficient and reliable methods of measuring wood moisture.

For relating wood properties to moisture content, the moisture content is defined as the weight of the water contained in the wood expressed as a percentage of the ovendry weight of the wood. Thus the moisture content may range from zero for ovendry wood to over 100 percent when the water in the wood weighs more than the wood substance.

The ovendrying method of measuring the moisture content of wood is generally accepted for basic laboratory work, or as a standard for calibrating other methods (_1_).[3] This method involves simply weighing the specimen before and after ovendrying. Because the quantities used for defining moisture content are measured directly, this method is the most precise known.

If wood has been treated or impregnated, ovendrying moisture measurements may be inaccurate. If the impregnant is volatile at oven temperatures, it will be evaporated and the resulting weight loss can be misinterpreted as due to evaporated water. If the impregnant is nonvolatile, it remains in the wood and increases the apparent ovendry weight of the wood. When the wood specimen has been so treated, the distillation method may be more accurate (_1_). The distillation method is also more accurate than the ovendry method on some species that naturally contain large amounts of volatile materials other than water.

These two basic methods of determining wood moisture have the disadvantages of being time consuming (the drying period alone is at least 24 h), requiring expensive apparatus and considerable skill in manipulation, and destroying the specimen. This prompted the search for other methods that were simpler and faster.

One method tried was to confine a strip of paper whose color indicated the relative humidity of its surroundings in contact with the wood; thus, the color of the paper indicated roughly the moisture content of the wood. Another method involved pulverizing the specimen and mixing it with a chemical that generated a gas when reacting with water. When this reaction took place in a closed container, the chemical extracted the water from the wood and the moisture content was determined by measuring the gas pressure produced inside the container. Another method was to place the specimen in a small closed container in which a humidity-sensing element was mounted. The relative humidity inside the container, as measured by the sensing element, was related to the moisture content of the wood. A variation of this method involved boring a hole in the specimen and using a small pump to circulate air into the hole past a humidity-indicating chemical or sensor.

The potential value of electrical resistance as a moisture indicator became evident when studies were made of the electrical properties of wood (_13_). It was found that the electrical resistance of wood depended on its moisture content, so a measure of electrical resistance could be used to indicate moisture content.

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[3] Italicized numbers in parentheses refer to Literature Cited at end of this report.

A resistance-type moisture meter differs from an ordinary ohmmeter only in the unusually high values of resistance that must be measured when checking wood below about 10 percent moisture content. First attempts to develop a portable instrument capable of measuring these high resistances began in the late 1920's and led to the "blinker-type" meter. This device consisted of a neon lamp in parallel with a high-quality capacitor that was charged through the wood specimen as a series resistor. When the capacitor voltage reached the firing voltage of the lamp, the lamp conducted briefly, thereby discharging the capacitor and starting the process over again. The time required to charge the capacitor increased as the series resistance increased, so the rate of flashing of the neon lamp indicated the electrical resistance of the wood.

Later, a high-resistance vacuum-tube bridge was developed that led to the modern direct reading resistance-type moisture meters (5). These instruments are basically resistance bridge circuits, using a wide range of standard resistors and a high resistance electronic voltmeter to measure the bridge output.

At about the same time as direct reading resistance-type meters appeared on the market, the dielectric-type meter was developed. This type of meter operated on the relationship between the dielectric properties and moisture content of wood.

Three types of electric moisture meters, each based on a different fundamental relationship, have been developed: The resistance type, which uses the relationship between moisture content and direct current resistance; the power-loss type, which uses the relationship between moisture content and the dielectric loss factor of the wood; and the capacitance type, which uses the relationship between moisture content and the dielectric constant of the wood. At present there are several manufacturers of portable resistance-type meters, and one manufacturer of portable power-loss type meters in the United States. No purely capacitance-type portable meter is being marketed at present, but one portable meter is available that is, in effect, a combination of capacitance and power-loss types; it is called the capacitive admittance type.

In addition to portable meters, stationary meters are available that monitor the moisture content of lumber moving along a conveyor, or that make remote measurements on lumber in a dry kiln. These meters operate on the same general principles as portable meters.

In the discussion that follows, the electrical properties that provide the basis for electric moisture meters, and the operating procedures for each type of meter will be described in more detail.

ELECTRICAL PROPERTIES OF WOOD

The electrical properties of wood important for electric moisture meters are the direct current resistance, the dielectric constant, and the dielectric loss tangent or power factor.

Electrical Resistance

Electric resistance is the property of a material that impedes the flow of electric current through the material. This requires that an electromotive force or electric potential difference exist across the material to cause a current to flow. In most cases, the magnitudes of resistance, electromotive force, and current are related by a simple proportion known as Ohm's law.

Effect of moisture content.--The direct-current resistance of wood varies greatly with moisture content below the fiber-saturation point. As the moisture content decreases from fiber saturation (about 30 pct moisture, based on the dry weight of the wood) to the ovendry condition, the resistance increases by a factor of over 10 million (table 1). In this range of moisture content, a rough linear inverse relationship exists between the logarithm of the resistance and the logarithm of the moisture content. At moisture content levels beyond fiber saturation, the electrical resistance correlates very poorly with moisture content. Increasing the moisture content from fiber saturation to complete filling of the capillary structure of the wood with free water typically decreases the resistance by a factor of 50 or less. This is true even though at complete saturation most species contain well over 100 percent moisture content based on the ovendry weight of the wood. Typical values of resistance at room temperature, using a moisture meter electrode on Douglas-fir, are 22,400 megohms at 7 percent moisture content and 0.46 megohm at 25 percent moisture content. Corresponding data for other species and levels of moisture content are given in table 1.

Effect of temperature.--The electric resistance of wood decreases as the temperature of the wood increases (4,10). This is opposite to the temperature effect on resistance in metals, and suggests that in wood the mechanism of conduction is by charge carriers whose number or mobility is increased by thermal activity. The conduction of current by wood is thus likely to be at least in part ionic. For moisture levels above about 10 percent, the resistance of wood is roughly halved for each increase in temperature of 10° C.

Effect of grain angle.--The resistance of wood parallel to the grain is about half that perpendicular to the grain. Ratios of resistance perpendicular to the grain, in relation to the longitudinal value, are about 1.8 for radial and 2.0 for tangential.

Dielectric Constant and Power Factor

The dielectric constant of a material is defined as the ratio of the capacitance of a capacitor using the material as the dielectric to the capacitance of the same capacitor with a vacuum (or practically, air) as the dielectric. In principle, the dielectric constant is a measure of how much electric potential energy (dipole moment per unit volume) is stored in the material when it is placed in a given electric field.

The dielectric power factor is a measure of the rate of dissipation of electric energy as heat within a dielectric material. When a dielectric material is placed in a constant electric field, it absorbs a certain amount of energy from the field and stores it as potential electric energy. With a perfect dielectric, this energy is completely recoverable when the field is removed. With practical dielectrics, however, some energy is lost in the store-recover cycle; this energy appears as heat within the dielectric material.

If the dielectric is in an electric field that is oscillating at a constant frequency, the dielectric will absorb and dissipate, from the field, power proportional to the product of the frequency and the loss factor. The power absorbed does not necessarily increase linearly or even monotonically with increasing frequency, however, because the loss factor may vary considerably with frequency (11).

Effect of moisture content.--Dielectric constant increases with increasing moisture content, the increase being at a much greater rate as the

Table 1.--The average electrical resistance along the grain in megohms, measured at 80° F. between two pairs of needle electrodes 1-1/4 inches apart and driven to a depth of 5/16 inch, of several species of wood at different values of moisture content.

Species of wood	Moisture content in percent																		
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Conifers:																			
Baldcypress	12,600	3,980	1,410	630	265	120	60	33	18.6	11.2	7.1	4.6	3.09	1.78	1.26	0.91	0.66	0.51	0.42
Douglas-fir (coast region)	22,400	4,780	1,660	630	265	120	60	33	18.6	11.2	7.1	4.6	3.09	2.14	1.51	1.10	.79	.60	.46
Fir, California red	31,600	6,760	2,000	725	315	150	83	48	28.8	18.2	11.8	7.6	5.01	3.31	2.29	1.58	1.15	.83	.63
Fir, white	57,600	15,850	3,980	1,120	415	180	83	46	26.9	16.6	11.0	6.6	4.47	3.02	2.14	1.55	1.12	.86	.62
Hemlock, eastern	....	120,000	20,000	4,300	1,300	450	200	100	45.0	25.0	14.0	8.8	5.40	3.50	2.30	1.60	1.10	.78	.57
Hemlock, western	22,900	5,620	2,040	850	400	185	98	51	28.2	16.2	10.0	6.0	3.89	2.52	1.58	1.05	.72	.51	.37
Larch, western	39,800	11,200	3,980	1,445	560	250	120	63	33.9	19.9	12.3	7.6	5.02	3.39	2.29	1.62	1.20	.87	.66
Pine, jack	450,000	52,000	9,500	2,800	1,000	440	210	110	60.0	35.0	21.0	13.0	8.80	5.80	3.80	2.60	1.80	1.30	.98
Pine, longleaf	25,000	8,700	3,160	1,320	575	270	135	74	41.7	24.0	14.4	8.9	5.76	3.72	2.46	1.66	1.15	.79	.60
Pine, red	700,000	100,000	17,000	4,300	1,300	470	210	100	52.0	28.0	16.0	10.0	6.80	4.40	2.80	1.90	1.20	.91	.67
Pine, white	20,900	5,620	2,090	850	405	200	102	58	33.1	19.9	12.3	7.9	5.01	3.31	2.19	1.51	1.05	.74	.52
Pine, ponderosa	39,800	8,910	3,310	1,410	645	300	150	81	44.7	25.1	14.8	9.1	5.62	3.55	2.34	1.62	1.15	.87	.69
Pine, shortleaf	43,600	11,750	3,720	1,350	560	255	130	69	38.9	22.4	13.8	8.7	5.76	3.80	2.63	1.82	1.29	.93	.66
Pine, sugar	22,900	5,250	1,660	645	280	140	76	44	25.7	15.9	10.0	6.6	4.36	3.02	2.09	1.48	1.05	.75	.56
Redwood	22,400	4,680	1,550	615	250	100	45	22	12.6	7.2	4.7	3.2	2.29	1.74	1.32	1.05	.85	.71	.60
Spruce, black	700,000	90,000	16,000	4,300	1,400	580	250	120	68.0	38.0	23.0	14.0	9.60	6.30	4.30	3.00	2.10	1.40	1.00
Spruce, Sitka	22,400	5,890	2,140	830	365	165	83	44	25.1	15.5	9.8	6.3	4.27	3.02	2.14	1.58	1.17	.91	.71
Hardwoods:																			
Ash, black	14,000	2,300	600	200	85	40	20	10	6.0	3.4	2.1	1.3	.90	.60	.42	.32	.25	.20	.17
Ash, white[1]	12,000	2,190	690	250	105	55	28	14	8.3	5.0	3.2	2.0	1.32	.89	.63	.50	.44	.40	.40
Aspen, bigtooth	300,000	24,000	4,000	1,100	360	150	60	30	16.0	8.6	5.0	3.1	2.00	1.30	.88	.61	.43	.33	.26
Basswood[1]	36,300	1,740	470	180	85	45	27	16	9.6	6.2	4.1	2.8	1.86	1.32	.93	.69	.51	.39	.31
Birch[1]	87,000	19,950	4,470	1,290	470	200	96	53	30.2	18.2	11.5	7.6	5.13	3.55	2.51	1.78	1.32	.95	.70
Birch, paper	200,000	24,000	5,000	1,400	550	230	110	57	30.0	17.0	10.0	6.0	4.00	2.50	1.70	1.10	.81	.59	.43
Elm, American	18,200	2,000	350	110	45	20	12	7	3.9	2.3	1.5	1.0	.66	.48	.42	.40	.40	.40	.40
Hickory[1]	....	31,600	2,190	340	115	50	21	11	6.3	3.7	2.3	1.5	1.00	.71	.52	.44	.40	.40	.40
Khaya[2]	44,600	16,200	6,310	2,750	1,260	630	340	180	105.0	60.2	35.5	21.9	14.10	9.33	6.16	4.17	2.82	1.99	1.44
Magnolia[1]	43,700	12,600	5,010	2,040	910	435	205	105	56.2	29.5	16.2	9.1	5.25	3.09	1.86	1.17	.74	.50	.32
Mahogany, (Swietenia)	20,900	6,760	2,290	870	380	180	85	43	22.4	12.3	7.2	4.4	2.69	1.66	1.07	.72	.49	.35	.26
Maple, sugar	72,400	13,800	3,160	690	250	105	53	29	16.6	10.2	6.8	4.5	3.16	2.24	1.62	1.23	.98	.75	.60
Oak, northern red[3]	14,400	4,790	1,590	630	265	125	63	32	18.2	11.3	7.3	4.6	3.02	2.09	1.45	.95	.80	.63	.50
Oak, white	17,400	3,550	1,100	415	170	80	42	22	12.6	7.2	4.3	2.7	1.70	1.15	.79	.60	.49	.44	.41
Philippine mahogany (Shorea spp.)	2,890	690	220	80	35	15	9	5	2.8	1.7	1.1	.7	.45	30	.21	.16	.12	.09	.07
Sweetgum	38,000	6,460	2,090	815	345	160	81	45	25.7	15.1	9.3	6.0	3.98	2.63	1.78	1.26	.87	.63	.46
Tupelo, black[3]	31,700	12,600	5,020	1,820	725	275	120	58	27.6	13.0	6.9	3.7	2.19	1.38	.95	.63	.46	.33	.25
Walnut, black	51,300	9,770	2,630	890	355	155	78	41	22.4	12.9	7.3	4.9	3.16	2.14	1.48	1.02	.72	.51	.38
Yellow-poplar[3]	24,000	8,320	3,170	1,260	525	250	140	76	43.7	25.2	14.5	8.7	5.76	3.81	2.64	1.91	1.39	1.10	.85

[1]Exact species unknown.

[2]Known in the trade as "African mahogany."

[3]The values for this species were calculated from measurements on veneer.

frequency of the applied field decreases (11). There is a roughly linear relationship between moisture content and logarithm of the dielectric constant at all frequencies, but the slope of the relationship increases as the frequency decreases (11).

The power factor usually increases with increasing moisture content, but at some combinations of moisture content, temperature, and frequency the reverse is true. Power factor is a nonlinear function of moisture, temperature, and frequency, and exhibits maximum and minimum values at various combinations of these variables.

Effect of density.--The dielectric constant of wood increases nearly linearly with increasing density, although a slight concave upward trend is apparent as the moisture content of the wood increases.

The power factor of ovendry wood increases rapidly with increasing density up to a density of about 25 pounds per cubic foot; above this density the power factor increases only slightly. At higher moisture levels, the power factor-density relationship becomes slightly concave upward.

The loss factor, being the product of two quantities that increase with density, also increases with density.

Effect of temperature.--The dielectric constant of wood increases with increasing temperature, except at very high moisture content where it is erratic and possibly reversed; the reversal could be related to the lowering of the fiber-saturation point at higher temperature (11). The increase in dielectric constant with increasing temperature indicates that thermally activated mechanisms of polarization are present. These mechanisms probably are interfacial polarization, where the external electric field causes ionic charge carriers to accumulate at internal discontinuities in the wood, and fixed dipole polarization, associated with orientation of polar cellulose molecules due to the external field. Other mechanisms of polarization, such as induced molecular dipole moment, exist in wood, but are not influenced by temperature.

As stated earlier in the paragraph on effect of moisture content, the power factor is not a simple function of temperature, but sometimes increases and sometimes decreases as the temperature increases, depending on frequency and moisture content.

Effect of species.--Most species with approximately equal density have similar electric properties, but there are exceptions. For example, silk-oak (*Grevillea robusta*) apparently contains unusually large concentrations of soluble salts or other electrolytes and has very unusual electric properties.

RESISTANCE-TYPE MOISTURE METERS

Portable resistance-type moisture meters are battery-operated, wide-range ohmmeters. Most models have a direct reading meter, calibrated in percent for one species, and with correction tables provided for other species. A portable resistance meter is illustrated in figure 1.

Electrode Design

To measure the electrical resistance of a wood specimen, the specimen must be arranged as an element in an electrical circuit. This requires electrical contact with the wood at two points, using a method of contact that produces consistent and meaningful results.

Surface contact electrodes are not generally usable with resistance-type meters, except possibly for use on thin veneer, because of the resistance gradients associated with wood drying under normal conditions. With surface

Figure 1.--A portable resistance-type moisture meter, with an electrode of two 1-inch pins; the electrode also has a depth-measuring probe between the pins.

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contacts, the generally drier, and hence vastly more resistive, surface dominates the measured resistance, and the only readings possible are of the dry surface. In general, surface electrodes on opposite sides of a flat specimen indicate the moisture content of the driest layer of wood between the electrodes.

Because of this limitation of surface contact electrodes, at least for thicker material, the electrode should penetrate into the wood. The simplest electrodes of this type have poles consisting of nail-like pins that are driven into the wood. This design is entirely satisfactory and is widely used because of its simplicity. Electrodes that are screwed into the wood are in limited use.

When pin-type electrodes are driven into wood, the observed resistance is almost exclusively in the thin shell of wood that is in immediate contact with the pin. Neither the resistivity of the wood between the poles of the electrode nor the distance between the poles has any significant effect on the reading of a resistance-type moisture meter.

Pin-type electrodes are driven into the specimen from one side, so the measured resistance is nominally in a plane parallel to the surface of the specimen and not across its thickness. Thus, the flow of electric current is parallel to the planes of nearly equal moisture content, assuming no gross anomalies in moisture distribution. Because of the steep resistance gradients in wood drying under normal conditions, practically all the current flows through the wettest layer of wood that is in contact with both poles of the electrode. If the wettest wood in contact with one pole of the electrode is at a different moisture content than the wettest wood in contact with the other pole, the drier of the two will limit the current and thus be responsible for the reading. Thus, it is important to reemphasize that the reading of a resistance-type moisture meter will be related to the wettest wood that contacts both poles of the electrode.

Wood of rectangular cross section that has been drying at a reasonably constant rate, and is everywhere drier than fiber saturation, will have a moisture distribution such that at a depth of one-fourth to one-fifth of its thickness the moisture content will be nearly equal to the average for the entire cross section. The corresponding depth for circular cross sections is about one-sixth of the diameter. Electrode pins should therefore reach these depths in order to indicate average moisture content (1).

Resistance data for calibrating resistance-type moisture meters have been obtained with the current flowing parallel to the grain. Therefore, when using meters of this type, the electrode should be oriented so that the current flows parallel to the grain. If the readings drift, take the reading immediately after the electrode is driven into the specimen.

Four-pin electrode.--One moisture meter electrode uses four steel phonograph needles that extend about 8 millimeters (5/16 in.) beyond their mounting chucks. Each pole of the electrode uses two of the phonograph needles or pins. The poles are about 3 centimeters (1-1/8 in.) apart and the two pins comprising each pole are about 1.5 centimeters (1/2 in.) apart. The structure of the electrode is a plastic material combining good mechanical strength and high electrical insulating value. A handle is attached for driving and extracting the electrode. The pin length of 8 millimeters is about one-fifth of the thickness of nominal 2-inch dimension lumber (actual thickness about 38 mm), so it is suited

for indicating the average moisture content for this thickness. The average moisture content of thinner material may be read by driving the pins to less than their full depth. The four-pin electrode is the one with which most resistance data have been obtained for calibrating resistance moisture meters, but its use in the field has declined in recent years.

Long two-pin electrodes.--Measuring the average moisture content of material thicker than nominal 2 inches requires a pin longer than 8 millimeters. Most meter manufacturers fill this need with an electrode with two pins, each comprising one pole of the electrode and about 25 millimeters long. To achieve the necessary strength, these longer pins are larger in diameter than the 8-millimeter-long pins. Two instead of four pins are used to permit the larger pins to be driven and extracted more easily. A two-pin electrode is illustrated in figure 1; this electrode features a central retractable probe that moves a scale for indicating the depth of penetration of the pins.

Despite the larger diameter and consequent larger contact area of the pins used in two-pin electrodes, readings using this electrode are consistently lower, by about 1/2 to 1 percent, than readings using the four-pin electrode (7). Apparently, doubling the contact area of a single pin is substantially less effective in reducing the net resistance than is duplicating the contact area with a second pin. Thus, when using any two-pin electrode, a correction of 1 percent moisture content should be added when the indicated moisture content exceeds 15 percent.

At least one manufacturer of resistance-type moisture meters offers a two-pin electrode with pins about 7.5 centimeters ([illegible] in.) long for use on poles, bridge timbers, and other large material.

Insulated-pin electrodes.--Some manufacturers offer electrodes with 25- or 75-millimeter pins that are covered by a tough insulating resin except at the tip. These electrodes are useful when testing lumber that has a high superficial moisture content, such as is caused by rain or dew. Such superficial films of high moisture are rarely detrimental to the usefulness of the lumber. With uninsulated pin electrodes, however, a resistance-type moisture meter would indicate these high surface moisture contents and could result in the lumber being rejected. Using insulated pins driven to the proper depth, a valid estimate of average moisture content may be obtained.

Even insulated pins cannot be used successfully on lumber with free water on the surface because the water will follow the pins as they penetrate the wood, giving a very high, misleading moisture reading.

Veneer electrodes.--For using a resistance-type meter on veneer, an electrode is supplied that consists of a large number of needles, each about 3 millimeters long, which are arranged into two groups; each group is one pole of the electrode. Normal calibration factors are assumed to be valid for this electrode.

Substitute electrodes.--When either the average or the core moisture content of a specimen with large cross section must be measured and the pins of the available electrodes are too short, two nails may be used for electrode pins. The nails should be driven to the proper depth, and about the same distance apart as the pins on the standard electrode. The reading then can be obtained by touching the standard electrode pins to the nailheads. It should be emphasized, however, that the reading is not influenced by the distance between the nails.

When using two nails, as when using any two-pin electrode, a correction of 1 percent should be added when the indicated moisture content is over 15 percent.

Useful Range of Resistance-Type Meters

The useful range of resistance-type moisture meters is from about 7 to about 30 percent moisture content, and only approximate qualitative readings may be obtained on wood with over 30 percent moisture content. The lower limit results from the difficulty in measuring the very high resistance involved, and the upper limit from the fact that the resistance is only a weak and erratic function of moisture content greater than fiber saturation.

DIELELECTRIC-TYPE MOISTURE METERS

The two basic types of dielectric moisture meters are the capacitance type and power-loss type. The former measures dielectric constant and the latter dielectric loss factor, both of which depend on moisture content. No portable model of the capacitance type is currently being marketed in this country, although there is one meter that responds primarily to the dielectric constant. This meter is usually referred to as the capacitive admittance type, and is essentially a combination of capacitance and power-loss types. All dielectric meters are sometimes referred to in the trade as "capacity-type," or "radiofrequency type" meters; neither term is accurately applicable to dielectric meters in general.

Capacitance type.--Moisture meters that use the relationship between moisture content and dielectric constant are called capacitance type. The wood specimen is penetrated by the electric field associated with the capacitor of the frequency-determining circuit of an oscillator when the electrode of the meter contacts the wood. The frequency of the oscillator is changed according to the effect of the specimen on the capacitance of this capacitor, or in other words, according to the dielectric constant of the specimen. A frequency discriminator generates a signal, read on a meter, proportional to the changes in frequency. Using the relation between dielectric constant and moisture, the meter can be calibrated to read moisture content. Due to technical problems and high cost, this type of meter is not at present being manufactured commercially.

Power-loss type.--Moisture meters that use the relation between moisture content and loss factor are called power-loss type meters. With these meters the wood specimen is penetrated by the electric field radiating from an electrode that is coupled to a low-power oscillator in the meter. Power absorbed by the specimen loads the oscillator and reduces its amplitude of oscillation which is in turn indicated by the meter dial. Since the loss factor depends on moisture content, the meter dial can be related to percent moisture.

A portable power-loss type moisture meter is illustrated in figure 2.

Capacitive admittance type.--The electrode of this meter is a capacitive element in a resistance-capacitance bridge circuit. When a wood specimen contacts the electrode, its capacitance and losses (admittance) are increased so the bridge is unbalanced in proportion to the dielectric

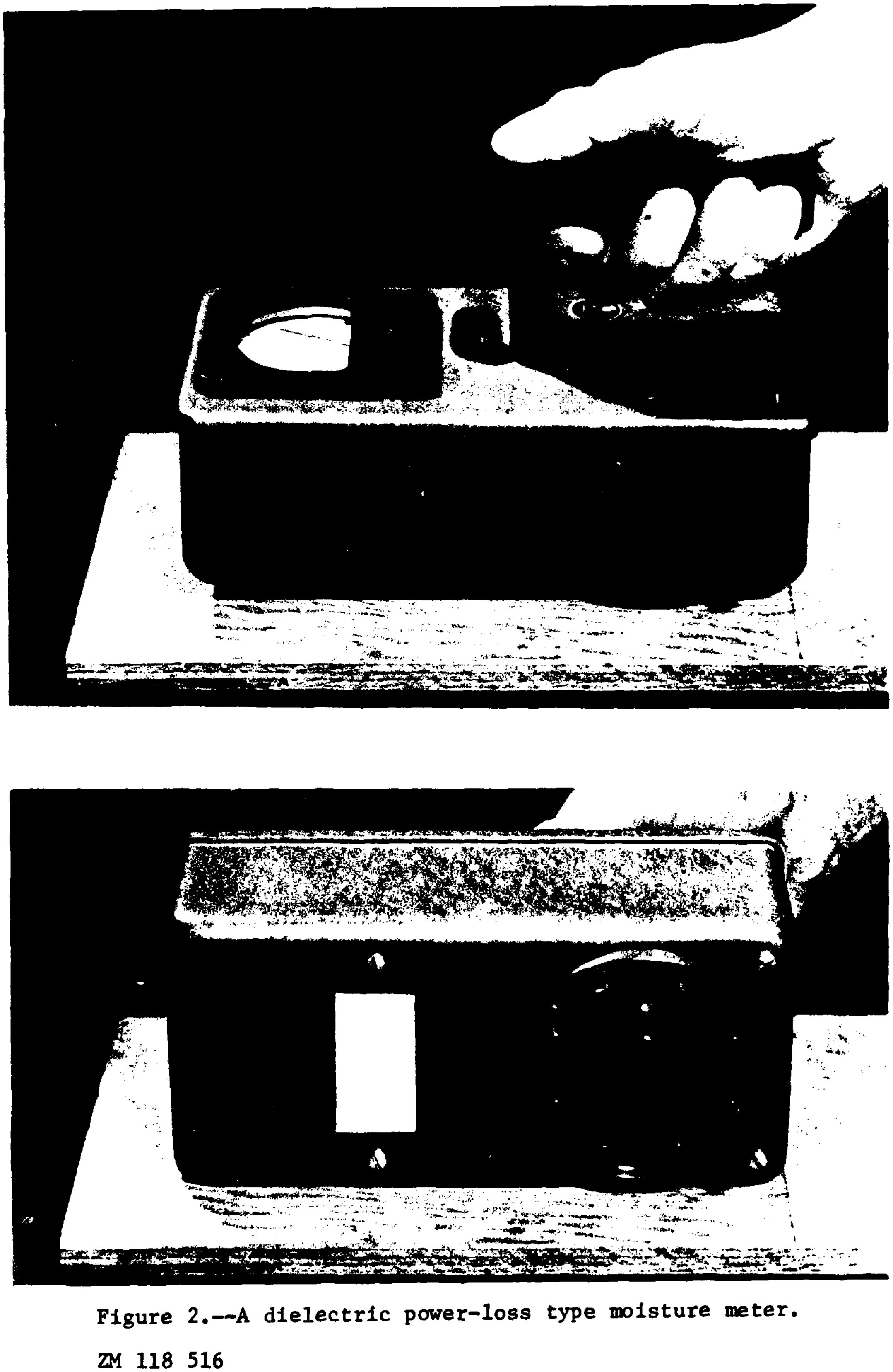

Figure 2.--A dielectric power-loss type moisture meter.

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constant and loss factor of the specimen. The meter dial reads the amount of bridge unbalance, which can be related to the moisture content of the wood specimen causing the unbalance.

A portable capacitive admittance meter is shown in figure 3.

Electrodes

Electrodes for dielectric type meters are of the nonpenetrating type. They vary in design according to particular applications, but are not interchangeable for use with one instrument, as are electrodes for resistance meters. The electrode of a dielectric meter is an integral part of the instrument.

For rough lumber.--This electrode on portable meters consists of a number of short, spring-loaded rods with the exposed ends rounded, mounted in a circular plastic plate about 7.5 centimeters (3 in.) in diameter. As the electrode is pressed into contact with the surface of the specimen, the spring-loaded rods are pushed into their mounting sockets in the plastic plate. Due to the restraining action of the springs, each rod maintains firm contact with the specimen surface. Thus, the rods adjust to irregularities in the surface making the calibration of the meter nearly independent of the shape of the surface.

A modification of this electrode consists of a single spring-loaded metal disk, about 25 millimeters (1 in.) in diameter, surrounded by a circle of smaller but similarly spring-loaded metal disks. This arrangement is mounted on a plastic plate about 9 centimeters (3-1/2 in.) in diameter.

The electric field from these electrodes penetrates about 2 centimeters (3/4 in.) into the specimen, so that specimen thicknesses up to about 4 centimeters (1-1/2 in.) may be used. With any surface contact electrode for dielectric meters, however, the surface layers of the specimen have a predominant effect on the meter readings, simply because the electric field is stronger near the electrode.

For smooth surfaces.--An electrode that gives slightly higher precision, but is usable only on smooth, plane surfaces is the quadrant type. This consists of the four quadrants of a 75-millimeter disk, separated slightly and independently free to move slightly, mounted on a plastic plate. The field penetration of this electrode is about 25 millimeters.

For veneer.--This electrode consists of several concentric rings, all in one plane, mounted on a plastic plate about 75 millimeters in diameter. The field penetration of this electrode is about 2 millimeters. When measuring the moisture content of material thinner than 3 millimeters (1/8 in.) with this electrode, it may be important to consider the material on the other side of the specimen. If this backup material is metal or a high loss dielectric, the reading of the moisture meter probably will be grossly in error. It is best to use a low loss backup material, such as rigid polystyrene foam.

For thick specimens.--This electrode consists of a ring of spring-loaded metallic disks surrounding a somewhat larger single disk in the center. It is similar to the electrode described earlier for rough lumber. The thick-specimen electrode differs only in that it is scaled up in size, so the field penetrates about 50 millimeters (about 2 in.).

General purpose electrode.--This electrode consists of a circular disk that in use is separated from the specimen by 2 or 3 millimeters of low-loss insulation. This separation makes the surface condition of the specimen less influential, so the electrode is usable on either rough or smooth surfaces.

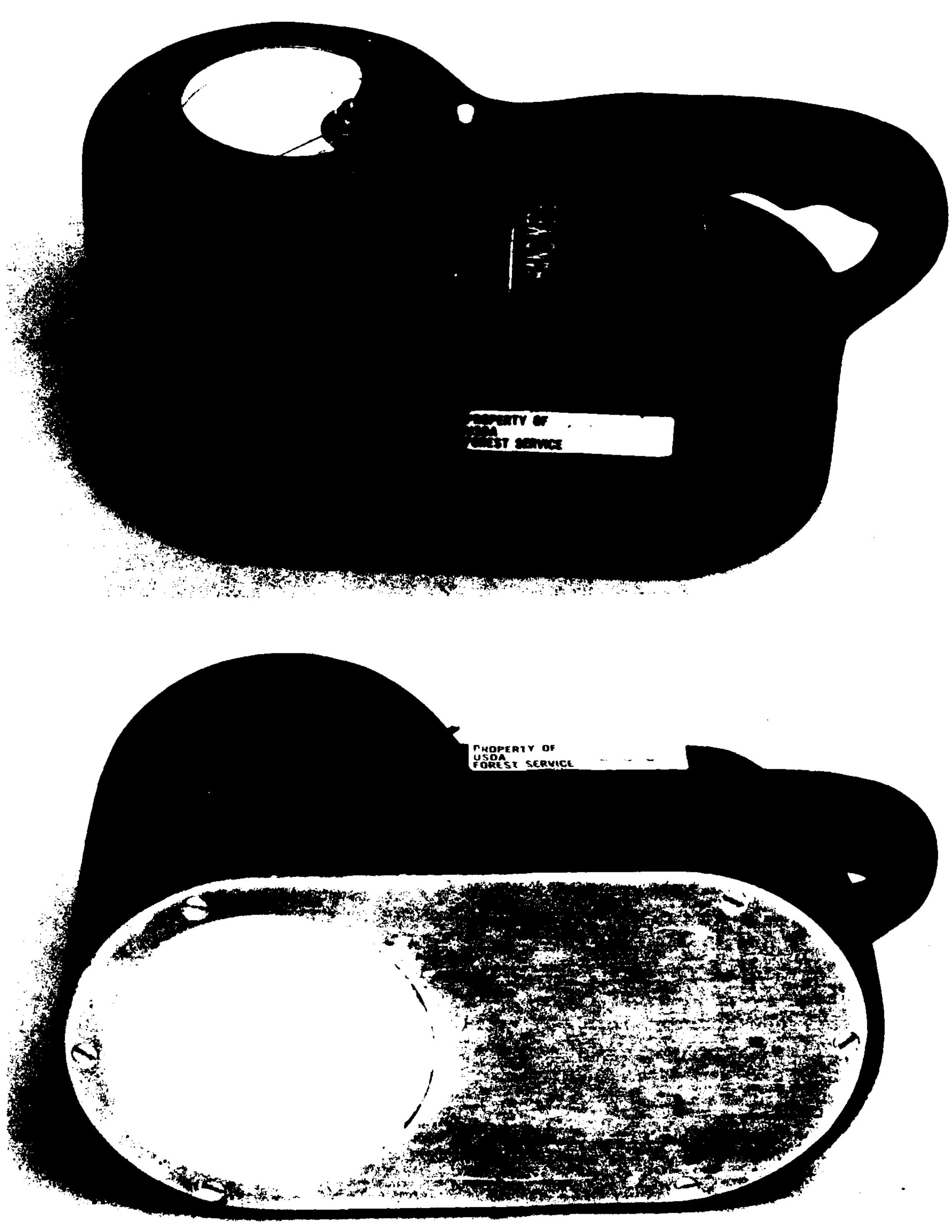

Figure 3.--A dielectric capacitive admittance type moisture meter.

M 141 438
M 141 439

Useful Range of Dielectric Moisture Meters

Dielectric moisture meters will read down to zero moisture, although at very low moisture levels the precision of the meters is reduced. Presently available power-loss meters have an upper range limit of about 15 to 30 percent moisture, depending on the species. The capacitive admittance meter is most precise in the range under 30 percent moisture content, but can give qualitative readings at moisture levels greater than 30 percent.

Nonportable Moisture Meters

Systems are currently available that continuously monitor the moisture content of material moving along conveyors and mark or eject individual pieces that are outside of moisture specifications. Both resistance type and dielectric type automatic moisture meters are available, but all use nonpenetrating electrodes. Typical systems are shown in figure 4. Systems are also available for monitoring the drying progress of lumber in a dry kiln, using either the resistance principle with permanently installed penetrating electrodes, or the alternating current impedance of the lumber using electrodes placed in the kiln loads.

ACCURACY OF MOISTURE METERS

The accuracy of an electric moisture meter in good condition is never limited by the ability of the meter to respond precisely to the fundamental electrical property of wood on which its calibration is based, nor by the precision to which the dial can be read. The accuracy is limited by the influence of factors other than moisture content on the readings of the meter, insofar as these factors are unknown or not properly taken into account.

One such factor is the calibration of the meter. This is usually considered the responsibility of the manufacturer, and the user accepts the calibration data supplied with the meter. The accuracy of calibration, especially as regards sampling and specimen control, is usually unknown to the user, and unless he is willing to run an involved calibration procedure himself (7,8), the influence of this factor remains outside his control.

There are some factors that affect the meter readings, however, that can be controlled by the user, and it is the intent of the following paragraphs to help minimize errors due to these factors.

Factors Affecting Accuracy

The principal factors other than moisture that affect the readings of electric moisture meters are: adequacy of sample, species, specimen density, moisture distribution, specimen thickness, temperature, electrode contact, grain direction, chemicals in the wood, weather conditions, and care or skill of operator. These will each be discussed briefly.

Adequacy of Sample

If all individual pieces in a lot of lumber were at the same moisture content, and moisture meters gave the same readings on all wood at the same moisture content, the moisture content of the entire lot could be determined by a single reading. But the moisture content of any lot varies from piece

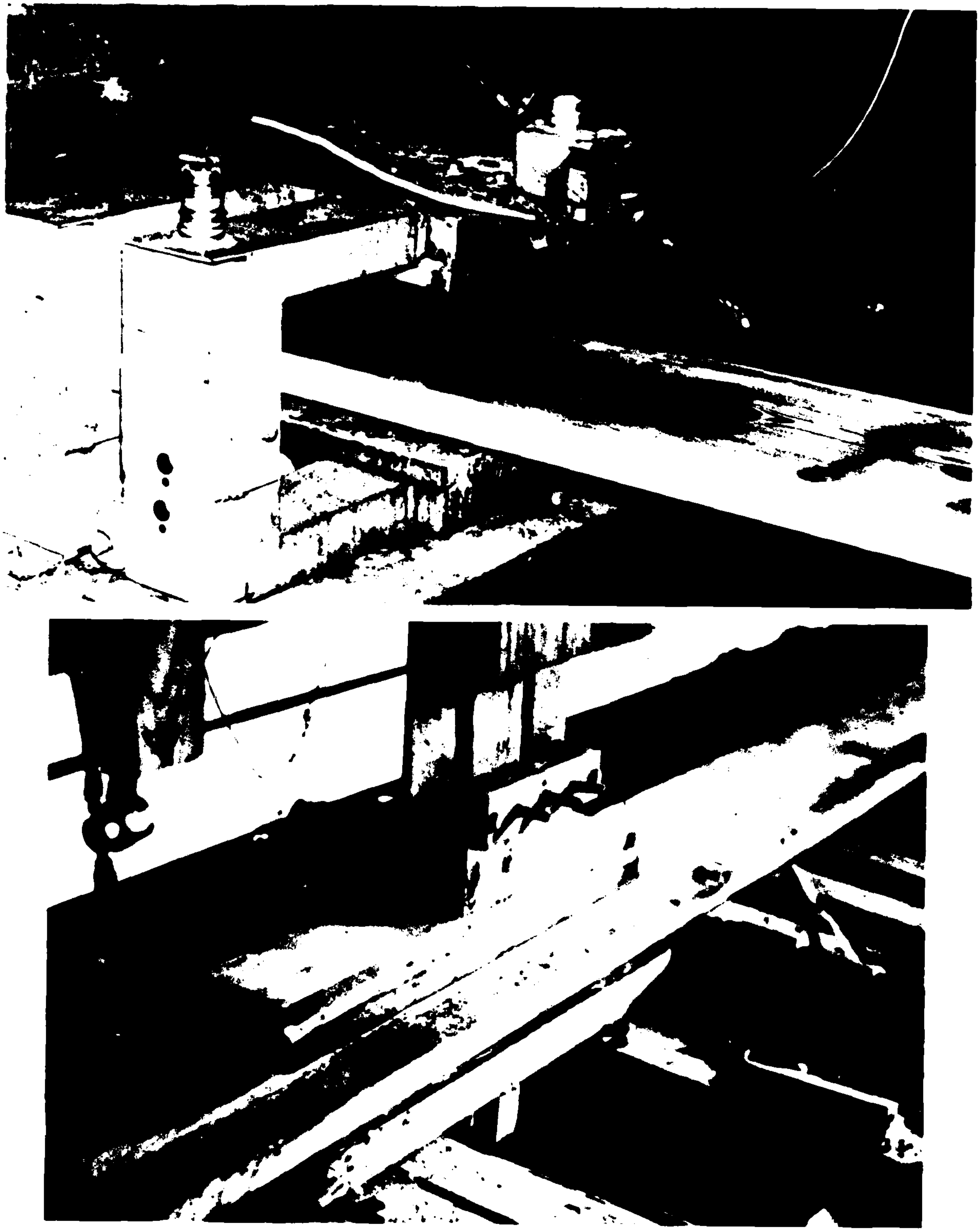

Figure 4.--Typical installations of nonportable moisture meters, for monitoring the moisture content of material moving along a conveyor. M 143 064 M 141 065

to piece, the moisture content of every piece varies from point to point throughout the piece, and moisture meters give various readings on different specimens at the same moisture content. For these reasons, an accurate estimate of the average moisture content of the lot requires more than one reading. A reading could be made on every piece in the lot, but usually the same information can be had for less cost by making readings on a smaller number of pieces, that is, a sample, properly selected from the lot.

Proper sampling entails selecting specimen pieces in such a way that in total they represent the lot without bias, and selecting a sufficient number of specimens to reduce the influence of variability to acceptable levels (6).

Selecting specimens.—If the sample is unbiased, the average of readings on the sample will differ from the average of all possible readings on the lot only because of chance, not some consistent effect of the sampling method. This condition can be assured if the individual specimens are selected from the lot purely by chance; that is, every piece in the lot has an equal chance of being in the sample.

Frequently a lot of lumber will consist of a number of subunits, such as kiln loads or fork-lift packages, and under these conditions an unbiased sample usually can be selected most easily by a process called stratified random sampling (6). This requires the lot to be divided into any number of roughly equal parts on the basis of some index of similarity (such as same kiln load), and then drawing two or more specimens, by chance, from each part. If for some reason the parts are not equal, the number of specimens from each part should be proportional to the number of individuals in the part. The basic requirement remains in any case that all individual pieces have the same probability of being in the sample.

Number of specimens.—The number of specimens required depends on the accuracy desired and the variability of the data.

The desired accuracy is arbitrary, but a reasonable and practical goal would be to have a probability of 0.95 that the sample average is within 1.0 percentage point of the average of all possible readings on the lot. Accepting this, the required sample size depends only on variability of the data.

In general the variability of the data will be unknown and can be estimated only from readings on a sample. The problem therefore reduces to drawing an unbiased sample of arbitrary size and determining from the observed variability of this sample whether more specimens are needed.

Statistically ideal computation of variability and sample size are too cumbersome for routine inspection of lumber, so the following approximate procedures are suggested.

Draw an unbiased sample of about 20 specimens, and record one reading from each; take all readings 50 centimeters (approximately 2 ft.) or more from the end of the piece. Then find the "range" by subtracting the smallest reading from the largest, square this difference, and divide it by 4. The resulting number is an estimate of the required sample size (6). If it is larger than 20, additional specimens are necessary to meet the desired standard of accuracy. If stratified sampling is used, the variance may be slightly overestimated by this method, so the estimate of sample size will be conservative.

If the lot to be inspected is quite small, it may be less costly to read every individual piece in the lot than to be concerned about proper sampling. If the lot is only a few pieces, two or more readings should be made at random on each. If the user desires, the same basic rules of sample size apply even to readings on a

single specimen, except that using range as an estimate of variability is rather unreliable for small sample sizes. On the other hand, concern about sample size on a single specimen is rather academic, inasmuch as more readings than statistically required may be obtained in less time than it takes to estimate the required sample size.

Species

At a given moisture content, both the resistance and dielectric properties of wood depend on species (7,8). The primary basis for this dependence is probably because species differ in structure and electrolyte concentration in the case of resistance, and with the additional variable of density in the case of dielectric properties. Because of the effect of species, species corrections should be made when the data are available.

If species corrections are not available, resistance meters may be used for approximate readings, because species corrections are usually less than 2 percent, especially for native North American grown species. Dielectric meters may also be used by assuming the calibration for a species of density similar to the specimens being tested, but the results will be reliable only as rough approximations. When a single species correction is applied to several species in a commercial group, the readings may be biased and less precise than if each species were considered separately.

Specimen Density

The readings of resistance meters are practically independent of specimen density. The readings of dielectric meters, however, are affected by the density of the specimen material. A substantial part, at least, of the species corrections for dielectric meters is actually a density correction. The species correction must, of course, be related to the average density of the species, and any single moisture determination will then be in error by an amount related to the deviation of the density of the specimen from the average for its species (or more precisely, the average of the sample used for calibration of the meter). The American firm manufacturing power-loss meters provides two species corrections for some widely used species, one for high-density specimens and one for low-density. Even if specimen density could be determined easily and reasonably accurately, however, available information is inadequate to permit more than an approximate correction to be made.

Moisture Distribution

High surface moisture, such as from rain or dew, forms a surface layer of low resistance and high dielectric constant and loss factor. This superficial moisture would in general cause electric moisture meters of any type to read much too high.

The average moisture content of a specimen with high superficial moisture may be read using a resistance-type meter equipped with an insulated pin electrode. If free water is standing on the surface, however, false readings are likely even with insulated pins.

Uneven moisture distribution along the length or width of a specimen may also result in meter readings that are grossly different from the true average. For this reason it is advisable, when individual readings are important, to make more than one determination on a given specimen.

Because of accelerated end-grain drying near the ends of specimens, moisture meter readings should not be made nearer than 50 centimeters from

the end, or one-half the length of the specimen, whichever is smaller.

Moisture gradients in wood that is drying may differ greatly from the expected form, causing readings of resistance meters at one-fourth to one-fifth of the thickness to differ greatly from the average moisture content of the cross section. This situation may be recognized by reading the meter as the electrode pins are driven progressively into the specimen. Deviation from a smooth increase in reading with deeper penetration, or a reading over 30 percent near the center, suggests that "the one-fourth to one-fifth thickness rule" cannot be considered reliable.

Irregular drying gradients have only minor effects on the readings of dielectric meters, as the reading is the integrated effect of all the specimen material penetrated by the field. The material nearest the electrode does have a predominant effect however, and in extreme cases (such as wet surfaces mentioned earlier) the reading could differ greatly from the average moisture content.

Specimen Thickness

The problem of specimen thickness is related to the problem of moisture distribution or gradient. If the specimen had a uniform moisture content, excessive thickness would not be a factor in the accuracy of the meter reading. With normal moisture gradients during drying, however, it is necessary to relate the thickness of the specimen to the depth at which the meter reads in order for the meter reading to be a valid estimate of the average moisture content.

Thus, it is necessary for the pins of resistance meter electrodes to be long enough to reach one-fifth to one-fourth of the thickness, and the field from dielectric meter electrodes should penetrate roughly to the middle of the specimen. With both types of instrument, the electrode should be selected to match the specimen thickness.

If dielectric meters are used on specimens that are much thinner than those used to calibrate the meter, the readings will be too small. As mentioned earlier, material behind thin specimens may also be important.

Temperature of the Specimen

As the temperature of wood increases, its electrical resistance decreases and vice versa (4,10-12). The effect of temperature is generally enough that temperature corrections should be made when using a resistance-type meter on specimens that are warmer than 90° F or cooler than 70° F. The amount of correction depends both on the temperature and moisture content, so it is best to determine the correction from a chart such as figure 5. If a chart is not available, a rough correction is to subtract 1 percent moisture content from the reading for every 20° F the specimen temperature is above the calibration temperature specified by the manufacturer and add 1 percent for every 20° F the specimen temperature is below the calibration temperature.

The effect of temperature on power-loss and capacitive admittance is more complicated than its effect on resistance, so temperature corrections for these meters are not as simple as for resistance meters. Temperature corrections for power-loss and capacitive admittance meters can be made using charts such as in figures 6, 7, and 8, or special tables that use the temperature effect to provide readings corrected for temperature (3).

When correcting for temperature the reading of any electric moisture meter, the meter indication should be corrected for temperature, and then the established room temperature-species

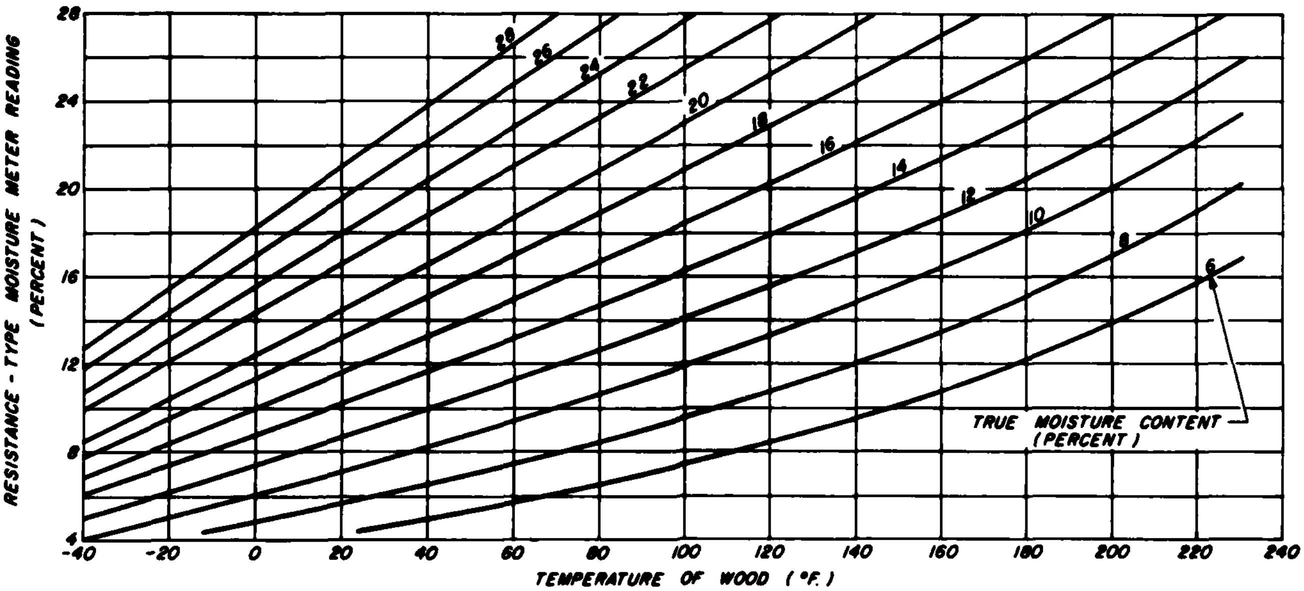

Figure 5.--Temperature corrections for reading of resistance-type moisture meters, based on combined data from several investigators. Find meter reading on vertical left margin, follow horizontally to vertical line corresponding to the temperature of the wood, interpolate corrected reading from family of curves. Example: If meter indicated 18 percent on wood at 120° F, corrected reading would be 14 percent. This chart is based on a calibration temperature of 70° F. For other calibration temperatures near 70° F, adequate corrections can be obtained simply by shifting the temperature scale so that the true calibration temperature coincides with 70° on the percent scale. For example, for meters calibrated at 80° F, add 10° to each point on the temperature scale (shift the scale 10° toward the left), and use the chart as before. After temperature correction, then apply the appropriate species correction.

M 76476 F

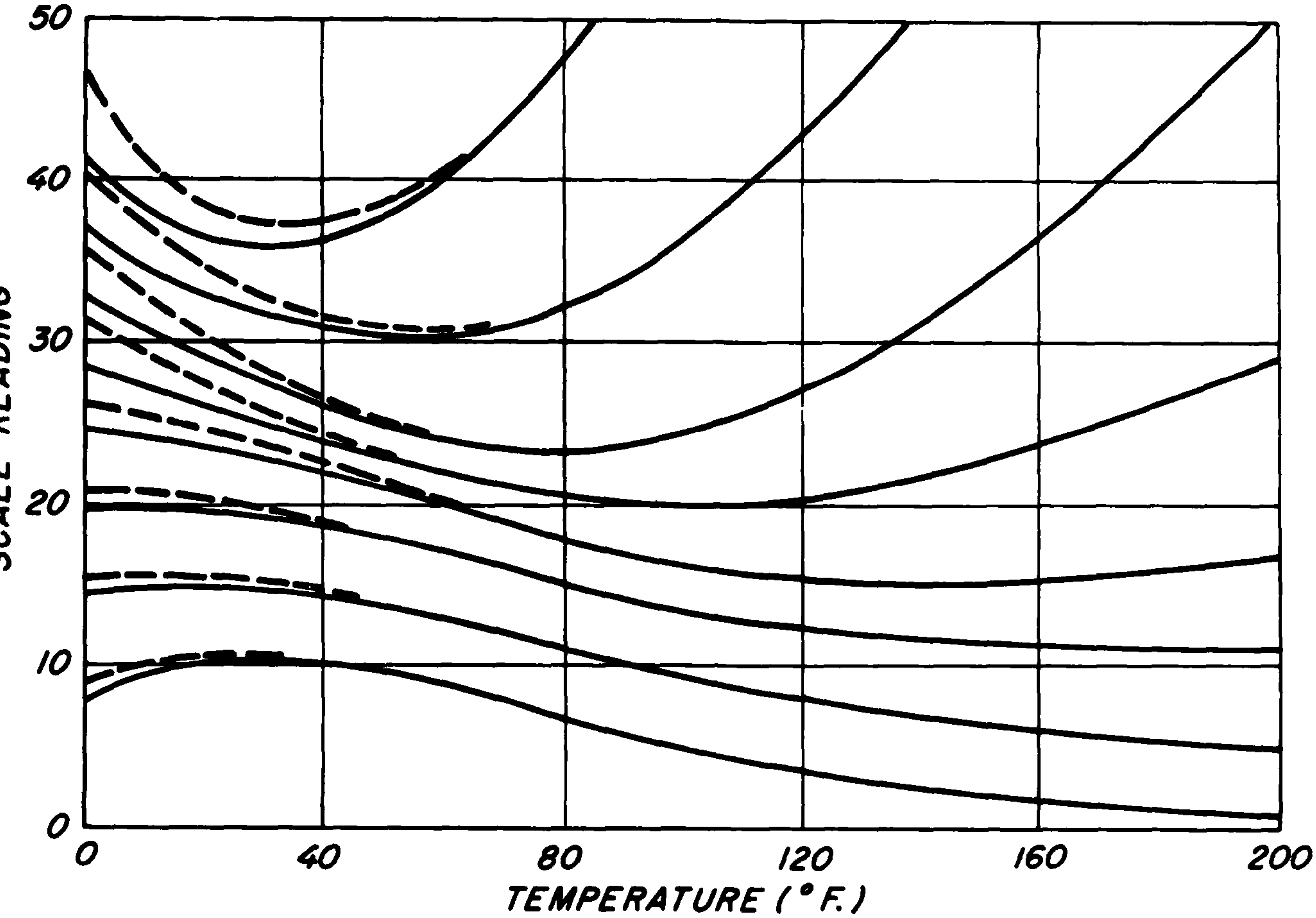

Figure 6.--Approximate temperature corrections for readings of power-loss type moisture meters; data taken using a Moisture Register model L. Locate the point whose coordinates are the observed scale reading and the specimen temperature, and trace back parallel to the curves to the calibration temperature of the meter (usually 80° F). The vertical coordinate here is the corrected scale reading, which is then converted to moisture content using the usual species conversion tables. Solid lines are for the meter itself at room temperature; dotted lines are for the meter at the same temperature as the specimens.

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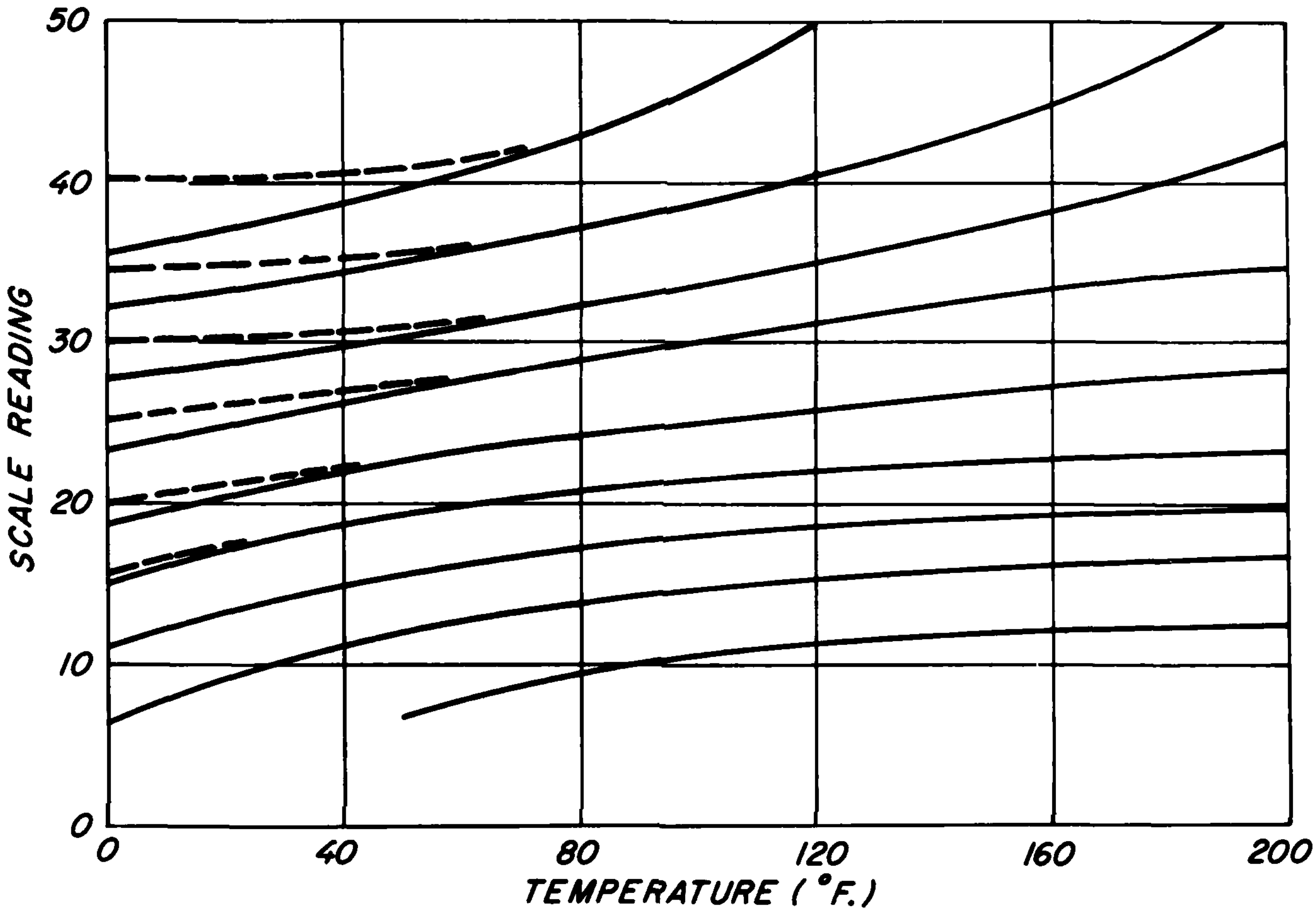

Figure 7.--Approximate temperature corrections for capacitive admittance meter; data taken using a "Sentry" hand meter with calibration setting of 20 or greater. Chart is used as figure 6.

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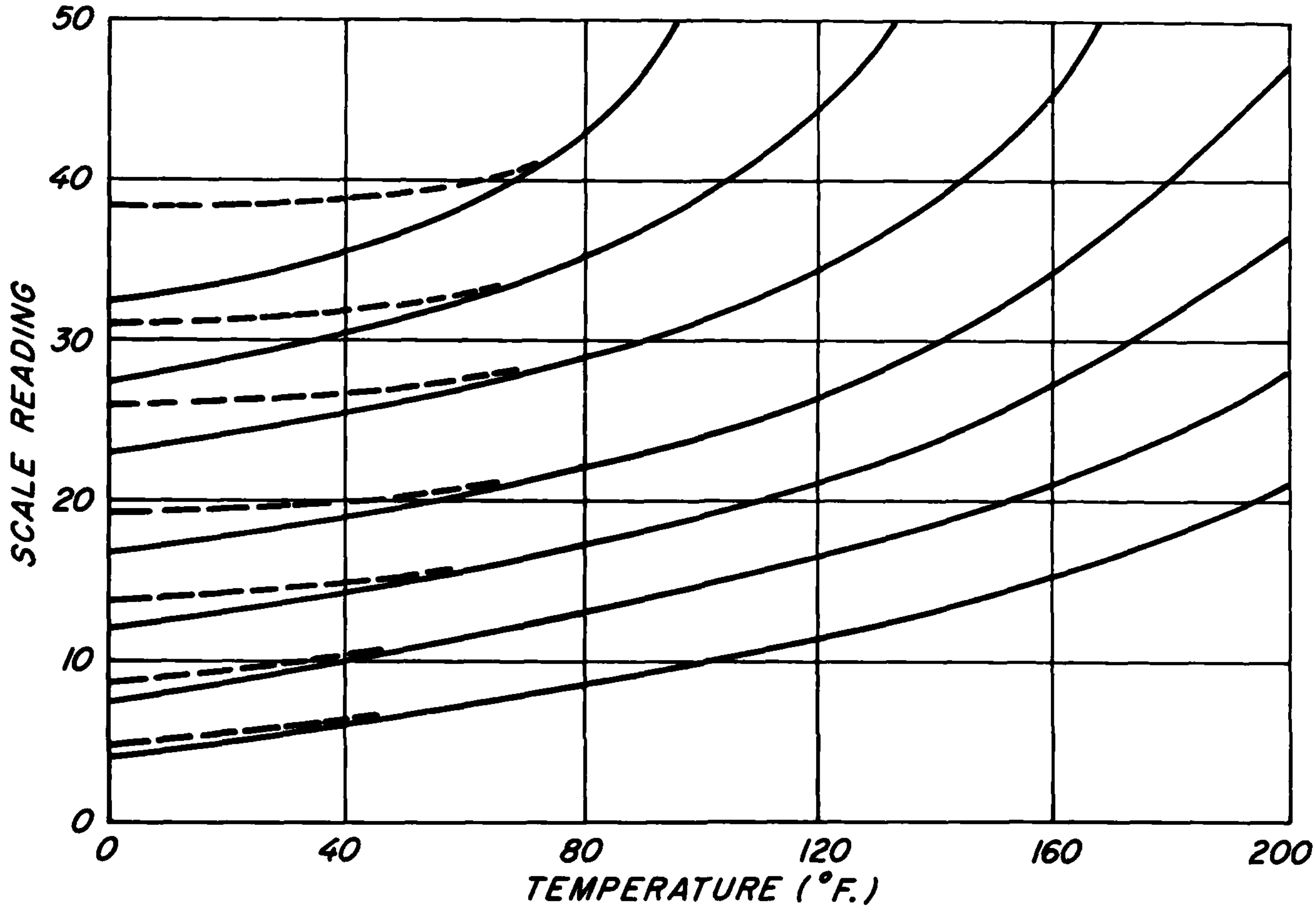

Figure 8.--Approximate temperature corrections for a capacitive admittance meter; data taken using a "Sentry" hand meter with calibration setting of 15 or less. Chart is used as figure 6.

M 134 530

corrections or calibration factors applied.

Temperature of the lumber also affects the calibration of in-line systems for monitoring moisture of lumber moving along conveyors. The limit settings should be adjusted for the temperature of the wood being monitored.

Electrode Contact

It is important for accurate readings that the electrode pins be driven to their proper depth into sound wood when using a resistance meter, and that the surface electrodes of dielectric meters be pressed firmly against the specimen. When a dielectric meter is used, the specimen should be larger than the electrode with an amount to spare on all sides at least equal to the specimen thickness. With all meters, only sound wood, free of decay, knots, and other defects, should be in actual contact with the meter electrode.

Grain Direction

Grain direction has no effect on the readings of dielectric meters, because the electrodes are symmetrical. With resistance meters, however, the electrode should be oriented so the current flows parallel to the grain whenever possible. At moisture levels below about 15 percent, the effect of grain direction is negligible. At moisture levels above 20 percent, readings across the grain may occasionally be as much as 2 percent moisture content lower than readings parallel to grain.

Chemical Treatments, Glues, and Finishes

Wood that has been treated with salts for preservative or fire retarding purposes or that has been in prolonged contact with seawater, will generally have lower resistance and higher dielectric constant and loss factor than untreated wood at the same moisture content. Consequently, electric moisture meter readings on wood so treated will generally be too high. The error increases with increasing moisture content, and is usually negligible when the wood is below about 8 percent moisture content. At moisture levels above 10 to 15 percent, the error becomes larger rapidly and erratically, making correction impossible. Oil-borne organic preservatives, such as creosote and pentachlorophenol, do not significantly affect the readings of electric moisture meters (9).

Some types of glue used in plywood are electric conductors, and may therefore affect the readings of electric moisture meters (2). The effect of plywood glue lines on the reading of a resistance meter may be determined by observing the meter reading as the electrode pins are driven into and then through the first ply. If the meter shows an abrupt increase in reading as the pins contact the glue line, moisture readings on that plywood will be unreliable. If no such effect is noted, the glue will not affect the readings.

Finishes rarely affect the readings of electric moisture meters. If it is suspected that a resin or metallic finish may be electrically conductive, the reading may be obtained using a resistance meter with insulated pins. The conductivity of the finish may be checked by just pricking the finish film with resistance electrode pins; a high moisture reading would then indicate a conductive finish, and no reading would indicate a nonconductive finish.

Doors, tabletops, or other panel products that include a metal lamination to provide resistance to heat, fire, or X-rays are apt to give false readings with electric moisture meters.

Weather Conditions

If electric moisture meters are used in foggy or rainy weather, or are moved from cool surroundings into warmer, more humid surroundings, films of moisture may form on parts of the meter. These films may then provide leakage paths that seriously affect the operation of the meter.

Usually these conditions may be recognized by difficulty in adjusting or balancing the meter, erratic or unstable zero settings, or no response from the meter when taking readings on material at low moisture levels.

Skill of Operator

Electric moisture meters are relatively easy to operate, and nearly anyone can learn to use them properly. The accuracy and reliability of the readings, however, do depend on the care exercised by the operator. Important points here are careful adjustment of the meter controls, proper application of necessary correction factors, ensuring proper application of the electrode, attention to the condition of the instrument, and, of course, the obvious importance of reading the meter correctly. Finally, the operator should select his specimen material carefully in order to achieve most efficiently the real objectives of the moisture measurements.

MAINTENANCE

The principal item of maintenance is replacement of defective or exhausted components of the instrument. Recalibration is rarely needed, especially with resistance meters, but the calibrations should be checked periodically using standards supplied by the meter manufacturers. Dielectric meters are usually provided with a built-in standard to check meter calibration.

Replacements and Repairs

Most portable electric moisture meters are powered by self-contained batteries. Dry batteries commonly will power the meter adequately for 6 months to a year of average use, but they should be replaced when adjustment controls must be set near the limits of their travel in order to adjust the meter correctly. Meters with rechargeable batteries should have the batteries charged on a routine schedule.

Vacuum tubes that are used in the older moisture meters are operated far below their rated power, and will normally give years of service. Occasional replacements will be required, however.

Electronic components other than tubes and batteries may occasionally fail. These should be replaced only by a competent technician.

The pins of resistance meter electrodes necessarily receive hard usage, and it is not uncommon for them to be bent or broken in use. It is always advisable to have spare pins and the installation tools in the meter case.

The electrode of any type of moisture meter should be kept clean to assure accuracy of the readings. The instrument should in general be handled carefully, as excessive rough handling can damage such fragile components as the meter movement or vacuum tubes.

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LIST OF MANUFACTURERS AND DEALERS HANDLING

APPARATUS FOR DETERMINING MOISTURE CONTENT OF WOOD

AND SUPPLIERS OF ELECTRIC MOISTURE METERS

The following partial list of manufacturers and dealers handling apparatus for determining moisture content of wood has been prepared merely for the information of correspondents, and the inclusion of names in it implies no endorsement as to quality or price. More extensive lists can be found in business directories.

Balances for Weighing 1-Inch Moisture Content Test Sections

Triple beam balance - capacity 1,111 grams - weighs to 1/100 gram
Laboratory balance - capacity 2,500 grams - weighs to 1/100 gram
Torsion balance - capacity 200 grams - weighs to 1/100 gram

Central Scientific Company, 2600 South Kostner Avenue, Chicago, IL 60623
Fisher Scientific Company, 203 Fisher Building, Pittsburgh, PA 17603
Ohaus Scale Corporation, 35 Hanover Road, Florham Park, NJ 07932
Schaar Scientific Company, 8200 South Hoyne, Chicago, IL 60634
Arthur H. Thomas Company, Vine at Third Street, Philadelphia, PA 19105
Torsion Balance Company, P.O. Box 535, Clifton, NY 07012
Henry Troemner, Inc., 6824 Greenway Avenue, Philadelphia, PA 19142

Automatic Balances for Weighing 1-Inch Moisture Content Test Sections

Arbor Laboratories, 3784 Fabian Way, Palo Alto, CA 94303
Central Scientific Company, 2600 South Kostner Avenue, Chicago, IL 60623
Fairbanks Weighing Division, Colt Industries, 700 East Street, Johnsburg Road, St. Johnsburg, VT 05819
Fisher Scientific Company, 203 Fisher Building, Pittsburgh, PA 17603
Mettler Instrument Corporation, 1 Princeton-Highstown Road, Highstown, NY 08520
National Controls, Inc., P.O. Drawer 1501, Santa Rosa, CA 95403
Pennsylvania Scale Company, 35 Graybill Road, Leola, PA 17540
Toledo Scale Company, P.O. Drawer 1705-1, Columbus, OH 43216

Scales for Weighing Kiln Samples

Platform scales or other types with capacity of about 35 pounds or 15 kilograms, graduated to 1/100 pound or to grams

Central Scientific Company, 2600 South Kostner Avenue, Chicago, IL 60623
Fisher Scientific Company, 203 Fisher Building, Pittsburgh, PA 17603
Mettler Instrument Corporation, 1 Princeton-Highstown Road, Highstown, NY 0852C

Suppliers of Various Types of Electric Moisture Meter

Portable, Resistance Type (including lumber and veneer)

Data Tech, Box 5130, Santa Ana, CA 92704-0130, (714) 546-7160 (Moisture Register products)
Delmhorst Instrument Company, 607 Cedar Street, Box 130, Boonton, NJ 07005, (800) 222-0638
Protimeter, Ltd., Meter House, Fieldhouse Lane, Marlow, Bucks, SL7LX, England
Forestry Suppliers, Inc., Box 8397, Jackson, MS 39204, (800) 647-5368
Lignomat, GmbH, D-7012 Fellbach-Oeffinger, Porschestrasse 6, Federal Republic of Germany
Jackson Wood Technology, 1616 Capital Avenue, Madison, WI 53705, (608) 233-8453 (Kit form)
Wagner Electronic Products, 326 Pine Grove Road, Rogue River, OR 97537

Portable, Power-Loss Type

Data Tech, Box 5130, Santa Ana, CA 92704-0130, (714) 546-7160 (Moisture Register products)

Portable, Capacitance (Capacitive Admittance) Type

Wagner Electronic Products, 326 Pine Grove Road, Rogue River, OR 97537, (503) 583-0541 (including Laucks "Sentry")
Kappa Janes, Limited, 27 Stewart Avenue, Shepperton, Middlesex, TW17 OEQ England

Semiportable, for Chips, Sawdust, etc.

Kappa Janes, Limited, 27 Stewart Avenue, Shepperton, Middlesex, TW17 OEQ England

Permanent, Kiln Monitors

Delmhorst Instrument Company, 607 Cedar Street, Box 130, Boonton, NJ 07005, (800) 222-0638
Irvington-Moore, Box 23038, Portland, OR 97223, (503) 620-0880
Wagner Electronic Products, 326 Pine Grove Road, Rogue River, OR 97537, (503) 582-0541

Permanent, Monitor of Moving Materials (including both lumber and veneer, both green and dry)

Wagner Electronic Products, 326 Pine Grove Road, Rogue River, OR 97537, (503) 582-0541
McCarthy Products Company, Box 15315, Seattle, WA 98115-0315, (206) 522-1700
Irvington-Moore, Box 23038, Portland, OR 97223, (503) 620-0800
Irvington-Moore, Box 40666, Jacksonville, FL 32203, (904) 354-2301

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U.S. Forest Products Laboratory.

Electric moisture meters for wood, by William L. James, Madison, Wis., FPL 1975.
28 p. (USDA FS Gen. Tech. Rep. FPL-6)

The moisture content of wood can be measured in terms of its electrical resistance or dielectric properties, which vary rather consistently with moisture contents under 30 percent. Readings can be affected by factors such as species, temperature, operator skill and others. Types of meters, variables, and suggestions for minimizing errors are discussed.

KEYWORDS: Resistance, electrodes, current, dielectric constant, capacitance, power loss, capacitive-admittance, portable, nonportable, sample selection.

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